Sacrificial Oxide etching compatible with Aluminum metallization

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SUMMARY

This paper reports on sacrificial oxide etching with very high selectivity to aluminum metallization using mixtures of 73% HF and IPA. Etch rate ratios up to 680 have been achieved even for (slow etching) thermal oxide. Thermal oxide etch rates up to 1.8 μm/min. are reported. Thick polysilicon accelerometers with aluminum metallization and thermal sacrificial oxide have been made as well as full aluminum microstructures using plasma oxide as sacrificial layer.

Keywords: *Sacrificial etching, compatible processing, sticking*

INTRODUCTION

One of the most difficult fabrication steps in surface micromachining is the sacrificial etch step and subsequent drying of the free standing structures. Especially when aluminum is used as the interconnect layer it is difficult to selectively etch the sacrificial oxide without attacking the aluminum. Drying of the devices after sacrificial etching also needs special attention because the capillary forces of water can cause the free standing structures to stick to the surface.

Metal attack

Traditional methods to prevent metal attack during sacrificial oxide etching are the protection of the metallization using resist [1] and the use of alternative etch mixtures like BHF/glycerol [2] and 'pad-etchants' [3]. However all these methods have disadvantages: Resist protection is only possible when etch times are limited to 10 minutes due to adhesion problems and etching of the resist itself [4]. Special etch mixtures can offer reasonable selectivity, but have a low oxide etch rate.

In the case of HF vapor etching the wafer is exposed to a HF vapor which etches the oxide and leaves the aluminum intact. This method has the advantage of avoiding the sticking problem since no fluid is used to etch the oxide. A disadvantage of this method is the non standard set-up of the process.

Concentrated HF mixtures

A new approach is to etch in highly concentrated HF solutions. In HF solutions aluminum is attacked via

$$2\,Al + 6\,H_3O^+ \Rightarrow 3\,Al^{3+} + H_2\uparrow + 3\,H_2O \qquad (1)$$

and oxide is etched by HF via

$$SiO_2 + 6\,HF \Rightarrow H_2SiF_6 + 2\,H_2O \qquad (2)$$

Since HF is a weak acid the H_3O^+ concentration in concentrated HF is relatively low, while the HF concentration is high. Thus in concentrated HF reaction (1), responsible for the aluminum attack occurs at a low speed, while reaction (2), responsible for the etching of oxide progresses rapidly. Therefore it should be possible to etch oxide with a high selectivity over aluminum in concentrated (73%) HF solutions. This technique approaches the method of HF vapor etching without the need of special equipment.

Sticking prevention

After sacrificial etching the devices need to be kept wet before further processing to avoid sticking which is caused by capillary forces pulling the structures down to the substrate during standard drying. The sacrificial etchant is removed in several dilution rinse cycles using DI water and ends with rinsing in a low surface tension fluid like IPA or acetone. These fluids make it possible to take the devices out of the rinsing fluid while maintaining a liquid film on the surface. In a last step the devices

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are dried in a special to prevent sticking. Practical drying methods include supercritical drying, freeze drying, and resist ashing.

EXPERIMENTS

In these experiments the highest commercially available HF concentration (73%) was used. In order to lower the etch rate and to lower the surface tension without a high increase in the H_3O^+ concentration the HF was diluted with various parts of IPA. A lower etch rate is advantageous when the underetch distance needs to be controlled by timing rather than by a physical etch stop. Adding IPA to the HF makes it possible to maintain a liquid film on the samples when they are taken out of the etchant, thereby avoiding the need for dilution rinsing.

The etch rate of thermal oxide and aluminum was measured and the etch selectivity was calculated. The same experiments were performed for mixtures of 40% HF and IPA. The results are summarized in tables 1 and 2. Figures 1 and 2 show the etch rates as a function of the IPA:HF ratio.

Table 1: Etch rates of oxide, aluminum and etch selectivity in mixtures of 73% HF and IPA. (nm/min.)

IPA : HF	Oxide	Aluminum	Selectivity
0 : 1	1500	2.2	680
1 : 1	833	12	69
2 : 1	167	18	9

Table 2: Etch rates of oxide, aluminum and etch selectivity in mixtures of 40% HF and IPA (nm/min.).

IPA : HF	Oxide	Aluminum	Selectivity
0 : 1	844	68	12
1 : 1	400	122	3
2 : 1	233	145	1.6

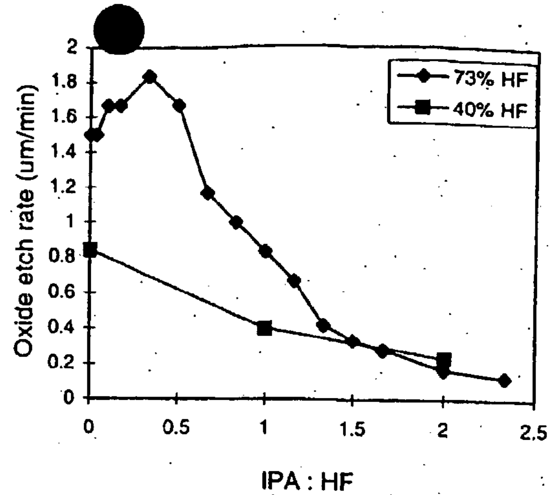

Figure 1: Oxide etch rates in 73% HF and 40% HF, diluted with IPA

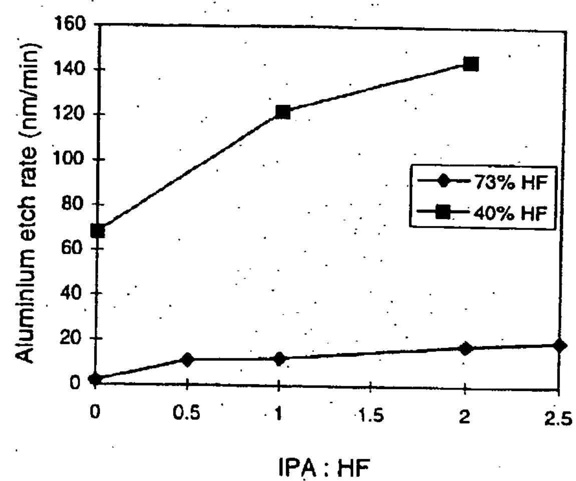

Figure 2: Aluminum etch rates in 73% HF and 40% HF, diluted with IPA

DISCUSSION

The highest selectivity is achieved for pure 73% HF. However, addition of IPA to the HF is preferred since this makes it possible to take the etched sample out of the etchant without the need of dilution rinsing. This saves chemicals and makes the process more suitable for batch fabrication. The decrease in etch rate makes it easier to control the underetch distance when a timed etch stop is used and the selectivity over aluminum is still acceptable when the 1:1 mix is used. For 40% HF concentrations (in water) the aluminum etch rate is higher due to the

increased H_3O^+ concentration. For lower HF concentrations (in water) the aluminum etch rate is even higher. From tables 1 and 2 can be concluded that the oxide etch rate is dominated by the HF volume concentration: 73% HF diluted with 1 part IPA has roughly the same HF concentration as undiluted 40% HF, leading to a comparable oxide etch rate. The initial increase in oxide etch rate for 73% HF with low IPA additions as shown in figure 1 can be explained by the increased wetting capability of this mixture, compared to straight 73% HF. The maximum measured thermal oxide etch rate is 1.8µm/min for 2 parts 73%HF with 1 part IPA.

To put the results in more perspective the etch rates are compared with etch rates reported in the literature of alternative etchants in table 3. From this table it is clear that pure 73% HF offers the best selectivity and highest etch rate.

Table 3: comparison between measured etch rates and values from literature.

Etchant	Oxide rate (nm/min)	Al rate (nm/min)	Selectivity
73% HF	1500 (thermal)	2.2	680
73% HF:IPA 1:1	833 (thermal)	12	69
BHF/glycerol [2]	95 (thermal)	.55	170
Pad etch [3]	200 (PSG)	5	40

FABRICATED STRUCTURES

To demonstrate the effectiveness of the 1:1 HF:IPA etching mixture, accelerometer structures were made using epipoly [5] as structural material and TEOS oxide as sacrificial material. The unprotected aluminum bondpads on the accelerometer were not visibly attacked during the 6 min. sacrificial etch which was needed to release the structure. After the 6 min etch the samples were taken out of the etch mixture and rinsed in IPA for 15 min, followed by a second 15 min IPA rinse. Rinsing in water is not possible as this would lead to rapid attack of the aluminum. Finally the samples were put into cyclohexane for 15 min and freeze dried on a -5°C cold plate under a nitrogen flow at atmospheric pressure. This freeze drying process, first proposed by Legtenberg [6], is a very simple sublimation process which does not need any vacuum equipment. In 5 min all the cyclohexane was sublimated and the samples were ready for packaging.

The design of a vertical capacitive epipoly accelerometer structure is shown in figure 3. A SEM photograph of the sensor with bondwires is shown in figure 4. The function of the perforations in the mass is to minimize air damping and to limit sacrificial etching time.

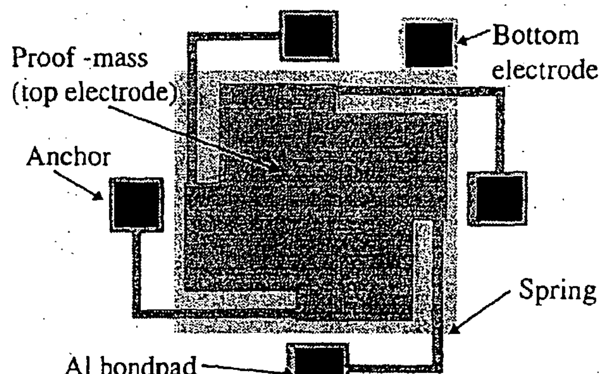

Figure 3: Layout of a vertical capacitive acceleration sensor

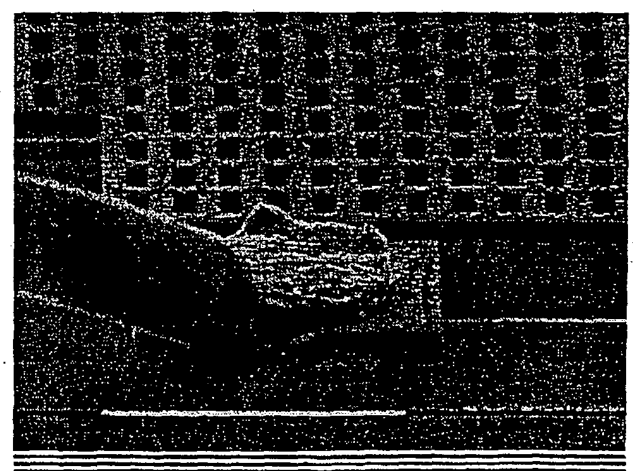

Figure 4: Epipoly vertical acceleration sensor with aluminum bondpad and bondwire.

With this technique it is also possible to fabricate microstructures entirely of aluminum. An example of an aluminum structure which was fabricated using PECVD oxide as sacrificial material is shown in figure 5.

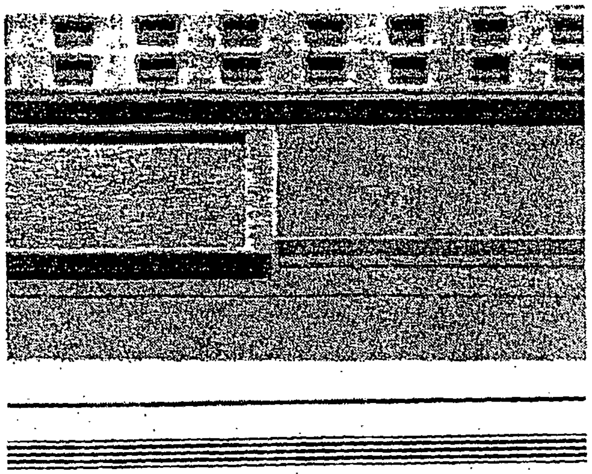

Figure 5: The same acceleration sensor as in figure 4, but now fabricated entirely in aluminum.

CONCLUSIONS

When high (73%) HF concentrations are used for sacrificial thermal oxide etching an etch selectivity up to 680 to aluminum interconnect can be achieved. The maximum measured etch rate of thermal oxide was 1.8 µm/min for a mixture of 2 parts 73%HF and 1 part IPA. Dilution rinsing before taking the sample out of the etchant is not needed when a mixture of 73%HF and IPA is used. This saves chemicals and simplifies the etching process altough this decreases the selectivity. The samples should not be rinsed in water, since water addition to the HF will result in rapid attack of the aluminum interconnect due to a higher H_3O^+ concentration.

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